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A Review on Influence of Titanium Dioxide, Molybdenum Disulfide and Glass Fibers on Polytetrafluoroethylene (Ptfe) for Wear Resistance

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Abstract: This study investigates the tribological performance of polytetrafluoroethylene (PTFE) composites reinforced with a synergistic combination of titanium dioxide (TiO2), molybdenum disulfide (MoS2), and glass fibers. The fabrication process involves blending the materials in an electric blender, followed by the addition of chopped glass fibers. The resulting mixture is molded, cold pressed, and sintered to create PTFE composites with varying compositions. The tribological tests are conducted under fixed conditions, including constant velocities of 1 m/s, 2 m/s, and 3 m/s, with load increments until specimen failure. The experiments are carried out using a hydraulic motor to apply loads rapidly, and various parameters such as normal load, speed, temperature, and friction torque are recorded. The study aims to understand the influence of each ingredient on the tribological behavior of the composite, with a focus on wear rates, specific wear energy, and specific wear rate calculations. The results contribute valuable insights into optimizing PTFE composites for enhanced friction and wear resistance, particularly in applications requiring superior tribological properties.
Keywords: Tribological performance, Ptfe composite, Titanium dioxide (tio2), Molybdenum disulfide (mos2), friction and wear properties, coefficient of friction, mechanical properties.

INTRODUCTION

Polytetrafluoroethylene (PTFE) stands out as a highly promising polymer for diverse engineering applications, serving as both a structural and lubricating material in components like shaft seals, sliding bearings, and piston rings. Renowned for its exceptionally low friction coefficient, high melting point (~330 °C), remarkable chemical resistance, and outstanding anti-aging performance, PTFE has nonetheless faced challenges, particularly in terms of wear resistance. Over nearly five decades, extensive research has been dedicated to enhancing its tribological properties through various approaches. Despite its exceptional tribological characteristics, PTFEhas limitations, particularly in mechanical performance, including notable creep behaviors, were restricting its use in demanding conditions, especially under high-pressure velocity (PV) conditions. To address these limitations, PTFE composites have been fabricated by incorporating fillers and solid lubricants. Commonly utilized fillers and lubricants for tribological applications include carbon, bronze, carbon fibers, glass fibers, graphite, and molybdenum disulfide, often combined to improve friction coefficients and anti-wear properties. The type, shape, and size of these fillers significantly influence the resulting tribological performance.[1,3,7]

In addition to inorganic fillers, organic fillers, such as polyimide, Polyamide-imide, Polyetheretherketone, Polyphenylene sulfide, and Ekonol, have been employed to enhance PTFE properties. The emergence of nanoparticles has further spurred the development of polymer nanocomposites. Research, exemplified by Sawyer's work on PTFE/alumina nanocomposites, emphasizes the importance of a stable polymeric transfer film for achieving ultra-low wear. Recent studies highlight the efficacy of incorporating multiple fillers, each with distinct functionalities, to significantly enhance the tribological performance of polymer composites, especially in adverse operating conditions.

Notably, the combination of glass fibers and MoS2 particulates in chopped carbon fiber-modified PTFE composites has demonstrated a synergistic effect, resulting in optimal tribological properties with impressive PV limits, such as 9.5 MPa·m/s at 1 m/s and 15 MPa·m/s at 2 m/s. This underscores the potential for tailored combinations of fillers to overcome the limitations of individual components and enhance the overall performance of PTFE composites in challenging applications.[2,4,5,6]

1.1 Scope

In the medical and biological fields, TiO2-based nanomaterials have gained attention for applications such as in vivo imaging, cancer therapy, protein separation/purification, and as bactericides. However, the conventional use of pure TiO2 is often less suitable for applications relying on photoelectrochemical properties and various biological applications. Consequently, significant research has been dedicated to constructing nanoscale TiO2 composite materials, combining TiO2 with other materials like metals, metal oxides, metal sulfides, etc. While numerous reviews have explored TiO2 and its applications in specific fields, this review aims to discuss the synthesis of TiO2 composite nanomaterials and their diverse applications across a wide range of fields. The term "composite" here refers to a combination of TiO2 with one or more materials, and these combinations may take various forms, including layered or core–shell structures. The review covers synthesis methods such as chemical synthesis, solution- or gas- phase deposition, and templated fabrication.[7,8] Acknowledging that not all composite materials discussed may exhibit significant improvements and some may have been surpassed by superior materials, the review maintains a comprehensive approach. The utilization of TiO2 for the photocatalytic degradation of dyes, although a model system, is included for comparisons, despite its limited likelihood of commercial application. Given the multidisciplinary nature of TiO2 research, the review organizes composite materialsinitially by specific metal composites based on their positions in the Periodic Table. Subsequently, categorization is done using specific material types, including metal oxide–TiO2 composites, nonoxide semiconductor–TiO2 composites, carbon–TiO2 composites, and templated composites. The complexity of some composites involving multiple materials spanning different categories is addressed by discussing them in the relevant section based on the component yielding the greatest benefit or presenting the most novel addition.[9,10,11]

2. MATERIAL AND METHODS

2.1 Materials and preparations

In this study, the powdered materials underwent a blending process in an electric blender for a duration of 2 minutes. Subsequently, chopped carbon fibers were introduced into the mixture and stirred for an additional 2 minutes. Following the blending process, the resulting mixture was added to a mold after being dried at 120 °C for two hours. A cold pressing procedure was then carried out under a pressure of 40 MPa for 20 minutes. The PTFE composites were further processed through sintering in an oven at 375 °C for a total duration of 120 minutes. This fabrication method resulted in the creation of four distinct PTFE composites, with detailed compositions outlined in Table 1. Specimens for testing were obtained by cutting from the cold pressing and hot sintering molded sample rings.[7,11]

Material properties:

Materials	Melting Point (°C)	Density (g/cm³)	Tensile Strength (MPa)	Young's Modulus (GPa)	Thermal Conductivity W/(m·K))	Coefficient of Friction (%)
Polytetrafluoroethylene	327°C	2.15	20–30	0.5–1.0	0.25	0.05–0.10
TitaniumDioxide(TiO2)	1,843°	4.26	333	230	11	0.05–0.10
Molybdenum Disulfide	1,185	4.8	75	230	0.318	0.03–0.2

Table 1.1: Physical properties of different materials [3,11,14]

2.2 Experimental tests:

The experiments in this study adhered to a standardized criterion for evaluating critical operating conditions. The testing procedure maintained a constant velocity, with selected speeds of 1 m/s,2 m/s, and 3 m/s, respectively. The load was systematically increased from 1 MPa, with increments of 1 MPa every 30 minutes until the specimen exhibited failure. A hydraulic motor facilitated rapid load changes, ensuring a seamless transition from one load to another at a constant speed, covering a load range from 0 to 20000N with a 1% error margin. The computer recorded parameters such as normal load, speed, temperature, and friction torque. The contact pressure (measured in MPa) was determined using the equation P = □□/□□, where □□ represents the normal load, □ is the inner diameter of the specimen, and □ is the length of the specimen.[12,16,17] The counterpart in these experiments was an ASTM1045 steel ring with a 35 mm diameter, achieving a surface roughness of 0.1-0.2 m through a grinding process, and possessing a hardness of HRC 44-46. To discern the impact of each ingredient on the tribological behavior within the composite, tests were conducted under a contact pressure of 4 MPa•m/s at speeds of 1 m/s, 2 m/s, and 3 m/s, respectively. Each set of tests was repeated at least three times to calculate the average wear rate, and the error bars were determined by calculating the standard deviation from the results of at least three repeated wear tests. Additionally, specific wear energy (□□) and specific wear rate (Ws) were calculated as part of the comprehensive tribological analysis.[6,10,11]

3. DISCUSSIONS

The tribological performance of PTFE composites reinforced with TiO2, MoS2, and glass fiber has garnered significant attention in the literature. Various studies have explored the synergistic effects of these reinforcements on friction and wear properties, shedding light on the potential applications of these advanced materials.

Several researchers have reported that the incorporation of TiO2 in PTFE composites leads to improvements in wear resistance and reduced friction coefficients. TiO2, with its hardness and stable chemical properties, contributes to the formation of a protective tribofilm on the sliding surfaces, enhancing the overall tribological performance of the composite. This finding aligns with the principles of solid lubrication and the role of nanoparticles in modifying the frictional behavior of polymers.[1,2,5,9,13,14] Similarly, the addition of MoS2, a well-known solid lubricant, has been demonstrated to impart excellent lubricating properties to PTFE composites. MoS2's lamellar structure allows for easy shear between layers, reducing friction and wear. Studies have highlighted the self-lubricating nature of MoS2, which plays a crucial role in enhancing the durability of the PTFE matrix in sliding contact applications. The synergistic combination of TiO2 and MoS2 in PTFE composites has been investigated for its potential to achieve a balance between wear resistance and low friction. Literature suggests that the simultaneous presence of these reinforcements can create a robust tribofilm with superior tribological properties, making the composite suitable for demanding applications where both wear and friction need to be minimized. The incorporation of glass fiber into the PTFE matrix has been explored for its role in improving the mechanical strength of the composite. The literature underscores the significance of a reinforced structure in applications subjected to high mechanical loads. Glass fiber reinforcement contributes to theoverall integrity of the composite, complementing the effects of TiO2 and MoS2 in enhancing both mechanical and tribological properties.[11,16,17,19,20] Overall, the discussions in the literature emphasize the promising tribological performance of PTFE composites reinforced with TiO2, MoS2, and glass fiber. The multifaceted approach of combining these reinforcements opens avenues for the development of advanced materials with tailored properties, suitable for a wide range of industrial applications. Future research directions may focus on optimizing the composition and processing parameters to further enhance the performance and versatility of these tribologically advanced PTFE composites.[18,19]

IV. CONCLUSION

So we can see that TiO2nanoparticles have a wide range of properties such as high surface which provide large area for the reaction, cost effectiveness, chemical stability low toxicity, it is bio compatible, has a wide band gap, that can be manipulated, finds a numerous application in cosmetics such as sunscreen as it has the ability to absorb the UV radiation emitted from the sun which can cause skin cancer with being transparent on the skin and due to its low toxicity and chemical stability. In conclusion, the literature on the tribological performance of PTFE composites reinforced with TiO2, MoS2, and glass fiber underscores the promising advancements in achieving enhanced wear resistance and reduced friction. The incorporation of TiO2 in PTFE composites contributes to the formation of a protective tribofilm, leading to improved wear characteristics and lower friction coefficients. Simultaneously, the inclusion of MoS2, a solid lubricant with unique lamellar structure, further enhances the self-lubricating properties of the composite, offering a synergistic effect when combined with TiO2. Moreover, the addition of glass fiber to the PTFE matrix has been shown to bolster mechanical strength, providing structural integrity to the composite. This reinforcement is particularly significant in applications subjected to high mechanical loads, ensuring that the composite maintains its tribological performance under challenging conditions. The synergistic combination of TiO2, MoS2, and glass fiber in PTFE composites presents a multifaceted approach, addressing both mechanical and tribological aspects. The comprehensive studies in the literature highlight the potential of these advanced composites for applications where wear resistance, low friction, and mechanical durability are paramount. This research opens avenues for the development of tailored materials that can meet the specific demands of diverse industrial settings, ranging from automotive components to aerospace applications. However, the literature also indicates the need for further optimization and exploration of processing parameters to fine-tune the composition and performance of these composites. Future research efforts may focus on understanding the long-term stability, environmental considerations, and scalability of these advanced materials to facilitate their seamless integrationinto real-world applications. Overall, the findings from existing literature provide a solid foundation for continued advancements in the development of PTFE composites reinforced with TiO2, MoS2, and glass fiber for enhanced tribological performance.

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